AMRL-TR-68-7

HUMAN EQUILIBRIUM DURING ACOUSTIC STIMULATION BY DISCRETE FREQUENCIES

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Foreword

This study was initiated by the Biomedical Laboratory, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The research was conducted by C. S. Harris and H. C. Sommer of the Biodynamics and Bionics Division, under Project 7231, "Biomechanics of Aerospace Operations," and Task 723103, "Biological Acoustics in Aerospace Environments." Acknowledgment is made of the assistance provided by Mr. George Kohlrizer of the University of Dayton Research Institute. Research covered herein was accomplished from November 1966 to February 1967.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory
Aerospace Medical Research
Laboratories

ERRATA - September 1968

The following corrections apply to Technical Report No. AMRL-TR-68-7, Human Equilibrium During Acoustic Stimulation by Discrete Frequencies.

Paragraph 4, page 9, should read as follows:

Whether or not future research finds 590 Hz to be a frequency that the vestibular system of normal individuals is particularly sensitive to, the results of the present experiment seem to support the sensitivity of vestibular systems of subjects at 1500 Hz to be a valid response. This result occurred within the frequency range where Ades (ref 1) reported that individuals perceived a slight shift in the visual field at the lowest intensity level.

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Abstract

The ability of subjects to balance on narrow rails was measured during exposure to pure tones of 100, 260, 590, 1500, and 2500 Hz and a control condition. One group of subjects was presented the test stimulus at intensity levels of 95 dB (re 0.0002 dyne/cm^2) in the left ear and 75 dB in the right ear (asymmetrical exposure). The other group was presented the tones at a level of 95 dB in both ears (symmetrical exposure), A decrement in rail performance occurred at 1500 Hz for the asymmetrical exposure group and at 590 Hz for the symmetrical exposure group. The decrement determined with symmetrical exposure was less than the decrement found with asymmetrical exposure. This result supports previous findings that asymmetrical exposure has more adverse effects on human equilibrium than symmetrical exposure. Both frequencies at which decrements occurred have been found in previous studies to have the lowest threshold for vestibular stimulation as determined by a slight shifting of the visual field in normal hearing subjects and by nystagmus measures in deaf individuals. Therefore, the results of the present study are interpreted as a possible demonstration of the direct effects of noise on the vestibular system.

SECTION I.
Introduction

Ades *et al* (ref 2) demonstrated that high intensity acoustic stimulation produced nystagmus in deaf subjects who had vestibular systems at least partially intact. Using pure tone stimulation, these authors found that 590 Hz was the most effective frequency for producing nystagmus. In various attempts to measure nystagmus in normal hearing subjects by the present investigators, pure tones, broad band noise, and interrupted tones at intensity levels up to 130 dB (re 0.0002 dyne/cm^2) were used as stimuli. No nystagmus was obtained at the intensity levels used in the experiments and the use of higher levels would have involved the risk of permanent hearing damage to the subjects. Therefore, an indirect measure of vestibular "involvement," a test of equilibrium, was used to determine this extra-auditory effect of high intensity acoustic stimulation.

A procedure developed by Graybiel and Fregley (ref 3) has been used for measuring the ability of subjects to balance on a series of narrow rails. These authors have presented evidence that performance on the rails is adversely affected by stimuli that seem to have their greatest effects on the vestibular system. The use of the Rail Task during exposure to high intensity broad band noise showed that this test was quite sensitive for measuring effects of the noise on the subject's ability to maintain equilibrium. A different intensity level of noise presented to each ear (asymmetrical exposure) produced a greater decrement in performance than an equal intensity level of noise presented to both ears (symmetrical exposure) (refs 4, 6). This result is consistent with those of an earlier study (ref 1) in which more pronounced subjective effects were reported with asymmetrical noise exposure.

A demonstration that the Rail Task is maximally sensitive to 590 Hz would seem to be evidence that the task is reflecting the direct effect of acoustic stimulation on the vestibular system. The results would be in agreement with the previous study (ref 2) where 590 Hz produced nystagmus in deaf subjects at a lower sound pressure level than the other frequencies used in the study. However, the vestibular system of deaf individuals may be maximally sensitive to different frequencies than the vestibular system of subjects with normal hearing. For example, in an early study normal hearing subjects were used in an attempt to determine the threshold of vestibular stimulation at several pure tone frequencies. Subjects showed the lowest threshold at 1000 to 1500 Hz when a slight shift in the visual field was used as a measure of vestibular stimulation (ref 1).

In the present investigation, rail task performance was measured at several frequencies to determine if information could be obtained that would clarify the response of the vestibular system of normal hearing subjects to acoustic stimulation. Test frequencies of 100, 260, 590, 1500, and 2500 Hz were used and the prediction was that the greatest decrement in performance on the rails would be found at 590 Hz or 1500 Hz or both. Also, the relative effects of asymmetrical versus symmetrical exposure were investigated at each of the frequencies.

SECTION II.
Method

SUBJECTS

Forty-eight male university students in their late teens through early twenties served as subjects in the experiment. These subjects were volunteers and were paid for their time. They had normal hearing as measured at audiometric test frequencies from 125 to 6000 Hz and less than a 5 dB difference in hearing threshold level between their right and left ears.

EQUIPMENT

The apparatus for producing the pure tone stimuli was assembled according to figure 1. An audio oscillator-amplifier was used to generate pure tone frequencies of 100, 260, 590, 1500, and 2500 Hz. The output of the oscillator-amplifier was directed to earmuffs housing PDR-10 receivers. A 100 dB attenuator (1 dB steps) in each channel provided independent level adjustments for each receiver (left and right). Calibration of each ear cup receiver assembly for each stimulus frequency was accomplished according to the following conditions by using an artificial ear flat plate assembly: asymmetrical group, left receiver 95 dB, right receiver 75 dB, and symmetrical group, 95 dB both left and right receivers (dB re 0.0002 dyne/cm^2). Calibration was checked periodically to assure that the SPL's had not changed and a frequency counter was used throughout the experiment to maintain the stimulus frequencies to an accuracy of $\pm$ 2 Hz.

Testing was conducted in a room 14 by 8 ft. in dimension with the walls and ceiling acoustically treated. Double doors attenuated noise transmission through the door entrance.

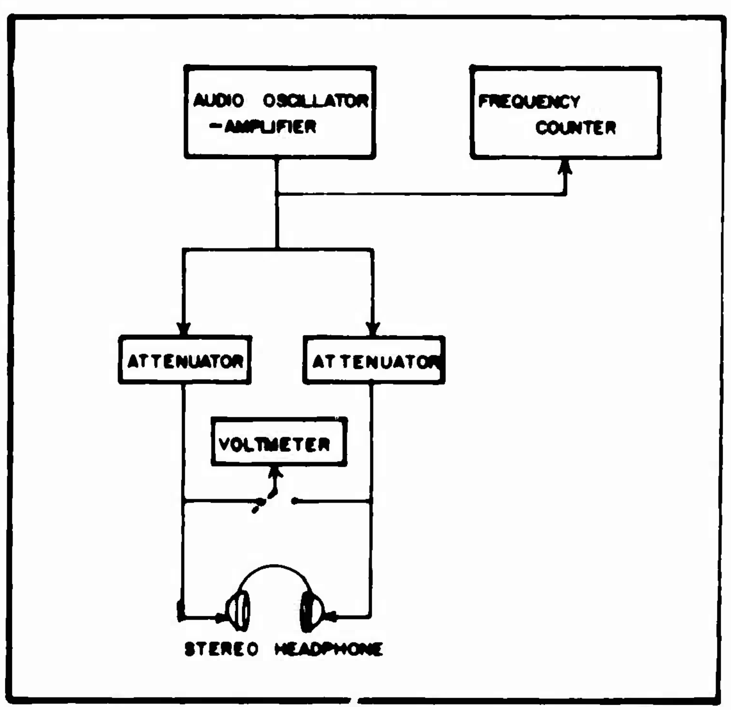

Figure 1. Equipment Used for Generation of Discrete Frequencies in Investigation.

PROCEDURE

Upon their first appearance at the laboratory subjects were given instructions about the nature of the experiment, then the rail task procedure was explained and the task was presented in exactly the same manner as in the experiment proper. To reduce possible anxiety due to exposure to pure tones at levels not ordinarily experienced in routine activities, subjects were exposed briefly to each of the pure tones used in the experiment. They were then required to fill out a paper and pencil measure for evaluating their subjective reactions to the tones and scheduled to return to the laboratory for six more sessions to perform the Rail Task while exposed to each of the stimulus frequency conditions used in the experiment.

The Rail Task was used in a previous experiment (ref 4) and was patterned after one developed by Graybeil and Fregley (ref 3). Subjects were required to balance on each of four rails in a heel-to-toe fashion with the arms folded across the chest. The experimenter measured the time from when the subject assumed the correct position of the rail until he violated his position by unfolding his arms, lifting a foot or stepping off the rail. A trial was terminated after 60 seconds if the subject was still balanced on the rail after this length of time. Five trials were administered on each of the four rails. On two of the rails, 2¼ inches wide and 1¾ inches wide plus a $\frac{1}{16}$ inch fiber glass cover, which had been added to keep the rails from splitting, the subjects were required to stand with their eyes closed. On the other two rails, 1½ inch wide and ¾ inch wide (plus the $\frac{1}{16}$ inch fiber glass cover), the subjects stood with their eyes open. Subjects were required to wear hard sole shoes and to wear the same shoes for all testing.

An eyes open score and an eyes closed score were determined for the purpose of analysis. The eyes open score was the total length of time in seconds the subject was able to balance on both rails in ten trials. The maximum possible score was 600 seconds (10 trials times the maximum possible score per trial of 60 seconds). The same procedure was used for determining the eyes closed score using the two larger rails.

Immediately upon completion of each test session on the Rail Task, subjects were asked to complete a subjective rating scale based on a semantic differential technique developed by Osgood *et al* (ref 7). "My Experience with the Noise" was rated on 16 scales of bipolar adjectives of the form bad-good, heavy-light, active-passive, and excitable-calm. Scoring was on a scale from 1 to 7; for example, a score of 1 on each of the above scales would indicate that the subject rated his experience with the noise as good, light, passive, and calm whereas a score of 7 on each of the scales would indicate that the subject rated his experience as bad, heavy, active, and excitable. Each subject's score was the mean of his ratings of the 16 bipolar adjectives. This rating scale has been used in prior experiments and has been assumed to be a measure of the stressfulness of the noise stimulus. The rationale for this assumption has been presented in previous papers (refs 4, 5).

Two groups of 24 subjects each were tested in the present experiment. The first group received a 95 dB intensity level in the left ear and a 75 dB intensity level in the right ear at all frequencies used in the experimental design. The second group was presented a 95 dB intensity level in both ears for the frequencies used in the experiment. In both experiments, each subject was presented the pure tones of 100, 260, 590, 1500, and 2500 Hz plus a control condition in which no audible tone was presented. The six experimental conditions were counterbalanced into six different orders of presentation. Four subjects were assigned to each order of presentation which resulted in 24 subjects for the asymmetrical group and 24 subjects for the symmetrical exposure group.

SECTION III.
Results

Friedman's Two-Way Analysis of Variance by Ranks (ref 8) was applied to all of the data obtained in the experiment. This nonparametric statistical technique was used because of the large variability of the Rail Task Measures (see table I containing means and standard deviations of the measures obtained in the experiment). Table II presents the results of the analysis. From this table, the eyes closed measures clearly revealed no sensitivity to the frequency of the pure tone stimulation. However, the X_r^2 of 10.17 obtained for the eyes open measure with asymmetrical exposure approach significance at the 5% level of confidence (11.07 required for significance at the 5% level). The Friedman Test for the data obtained for the eyes open measure with symmetrical exposure yielded a X_r^2 of 6.62 ($p<.30$). Although the values obtained did not reach customary levels of statistical acceptability, it was decided to test differences between frequencies of pure tone stimulation because mean differences were large and the greatest decrement occurred at the expected frequencies of 590 and 1500 Hz (see figure 2). The difference scores between frequency of pure tone stimulation were analyzed by use of a Sign Test (ref 8). The results of this analysis can be seen in table III for the eyes open measure and the subjective measures. For the eyes open measure with asymmetrical exposure, it can be seen that a significant decrement at 1500 Hz was obtained relative to the control group ($p<.01$) and that 1500 Hz also differed significantly from 100 and 590 Hz ($p<.05$). There was no significant difference between the results obtained at 1500 Hz and the results obtained at 280 and 2500 Hz. The difference, however, was in the expected direction with $p<.10$ and $p<.20$ obtained, respectively. In the symmetrical exposure group 590 Hz differed significantly from the control condition and did not differ significantly from the other frequencies used in the experiment.

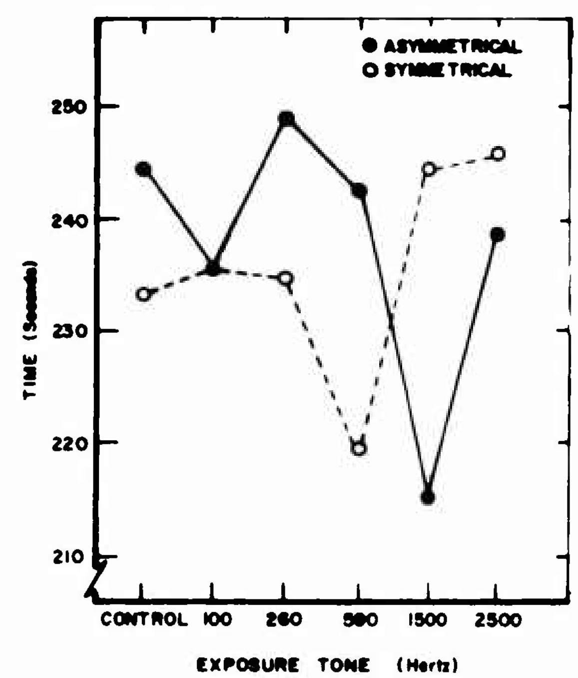

Figure 2. Mean Performance for Eyes Open Measure for Each Stimulus Frequency for Asymmetrical and Symmetrical Exposure.

TABLE I.

MEANS AND STANDARD DEVIATIONS FOR THE RAIL TASK MEASURES AND THE SUBJECTIVE MEASURES OBTAINED IN THE EXPERIMENT

	Control		*100 Hz*		*260 Hz*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Eyes Open Asymmetrical	244.58	147.88	235.96	149.84	249.08	142.47
Eyes Open Symmetrical	233.54	69.62	236.25	73.03	234.96	84.46
Eyes Closed Asymmetrical	174.42	111.84	164.33	130.60	180.46	115.97
Eyes Closed Symmetrical	190.71	87.68	172.08	81.19	165.50	63.18
Subjective Measure Asymmetrical	3.80	0.57	3.66	0.63	3.75	0.51
Subjective Measure Symmetrical	3.47	0.75	3.77	0.60	3.75	0.59

	590 Hz		*1500 Hz*		*2500 Hz*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Eyes Open Asymmetrical	242.71	141.89	215.29	130.18	238.75	160.02
Eyes Open Symmerical	219.62	75.03	244.62	87.86	246.04	75.35
Eyes Closed Asymmetrical	181.46	110.65	164.17	97.80	170.62	112.99
Eyes Closed Symmetrical	178.92	81.47	186.79	92.20	185.79	85.11
Subjective Measure Asymmetrical	4.08	0.59	4.53	0.67	4.45	0.65
Subjective Measure Symmetrical	4.22	0.72	4.75	0.72	4.54	0.64

TABLE II.

RESULTS OF FRIEDMAN'S TWO-WAY ANALYSIS OF VARIANCE FOR RANKS

95-75	X_r^2	*P*
Eyes Open	10.17	p<.10
Eyes Closed	3.76	p>.50
Subjective	52.81	p<.001
95-95		
Eyes Open	6.62	p<.30
Eyes Closed	3.26	p>.50
Subjective	42.21	p<.001

TABLE III.

RESULTS OF SIGN TEST

Eyes Open Asymmetrical Exposure	Control	*100 Hz*	*280 Hz*	*590 Hz*	*1500 Hz*	*2500 Hz*
Control		NS	NS	NS	.01	NS
100 Hz			NS	NS	.05	NS
280 Hz				NS	NS	NS
590 Hz					.05	NS
1500 Hz						NS
2500 Hz						
Eyes Open Symmetrical Exposure						
Control		NS	NS	.05	NS	NS
100 Hz			NS	NS	NS	NS
280 Hz				NS	NS	NS
590 Hz					NS	NS
1500 Hz						NS
2500 Hz						
Subjective Measure Asymmetrical Exposure						
Control		NS	NS	NS	.001	.005
100 Hz			NS	.001	.001	.001
280 Hz				.05	.001	.001
590 Hz					.005	.05
1500 Hz						NS
2500 Hz						
Subjective Measure Symmetrical Exposure						
Control		NS				
100 Hz			NS	.001	.001	.001
280 Hz			NS	NS	.001	.001
590 Hz				.05	.001	.001
1500 Hz					.005	.01
2500 Hz						NS

In the present study the time scores for both rails have been combined to obtain the eyes open measure because in a previous study the sum of the time on both rails proved to be more reliable than the scores obtained on each rail taken individually. However, because of the questionable significance levels obtained in the present study, the scores for each rail are presented in graphical form in figure 3. In the figure the mean performance for each rail ($1\frac{1}{4}$ and $\frac{3}{4}$ inch) is presented for asymmetrical and symmetrical exposure. The smallest mean time the subjects could stand on the $1\frac{1}{4}$ inch rail and could stand on the $\frac{3}{4}$ inch rail occurred at the same frequency of 1500 Hz for symmetrical exposure. The results obtained with symmetrical exposure show the lowest mean time at 590 Hz for the $1\frac{1}{4}$ inch rail, while there are clearly no differences across frequency for the $\frac{3}{4}$-inch rail.

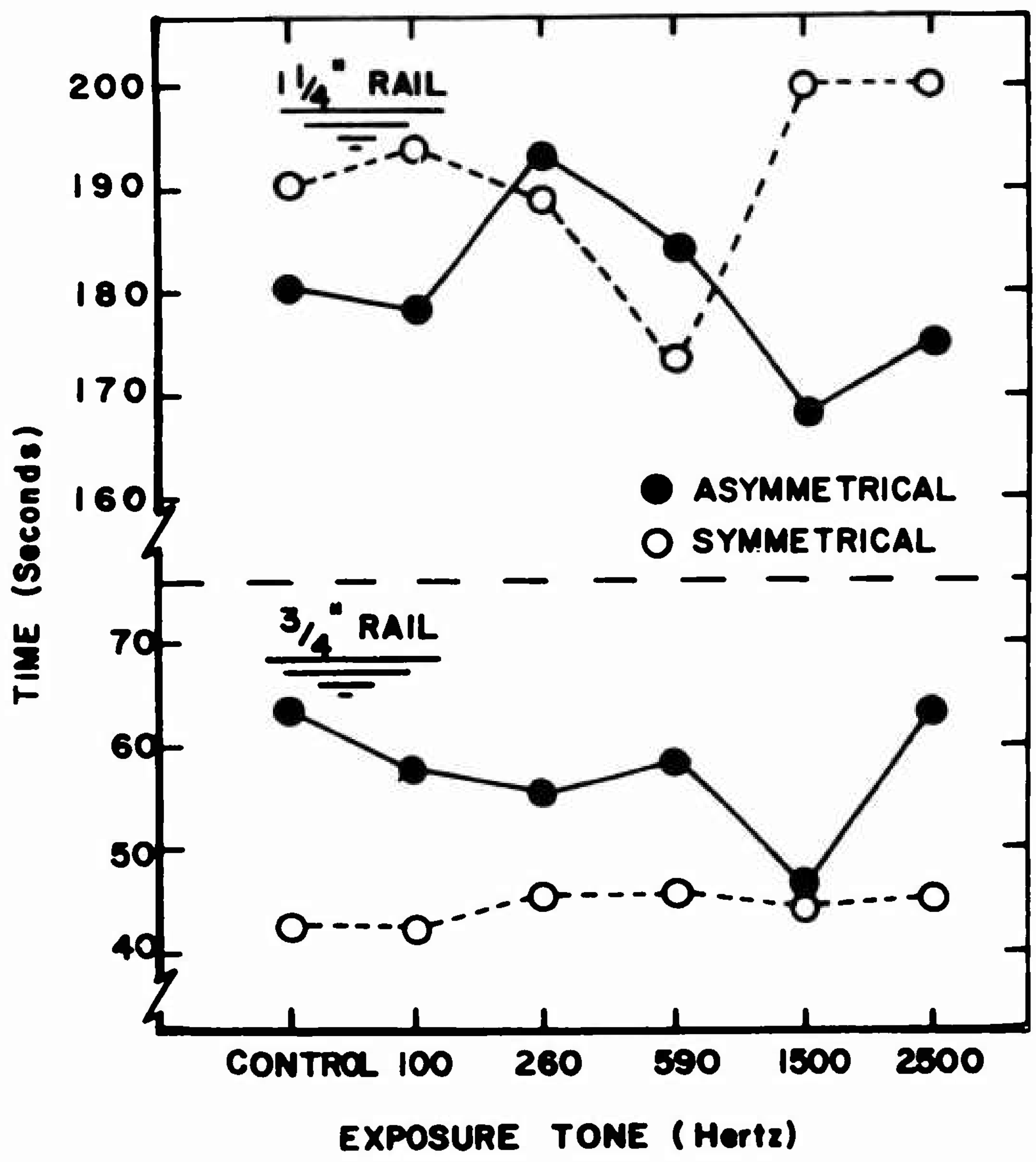

Figure 3. Mean Performance for Eyes Open Measure for the Independent Rails for Asymmetrical and Symmetrical Exposure.

The subjective measure clearly revealed greater sensitivity to frequency of pure tone stimulation than did Rail Task performance (see tables II and III). The curves for the asymmetrical and symmetrical exposure conditions show essentially the same pattern with the three higher frequencies of 590, 1500, and 2500 Hz receiving higher ratings than the control condition and the lower frequencies of 100 and 260 Hz (see figure 4).

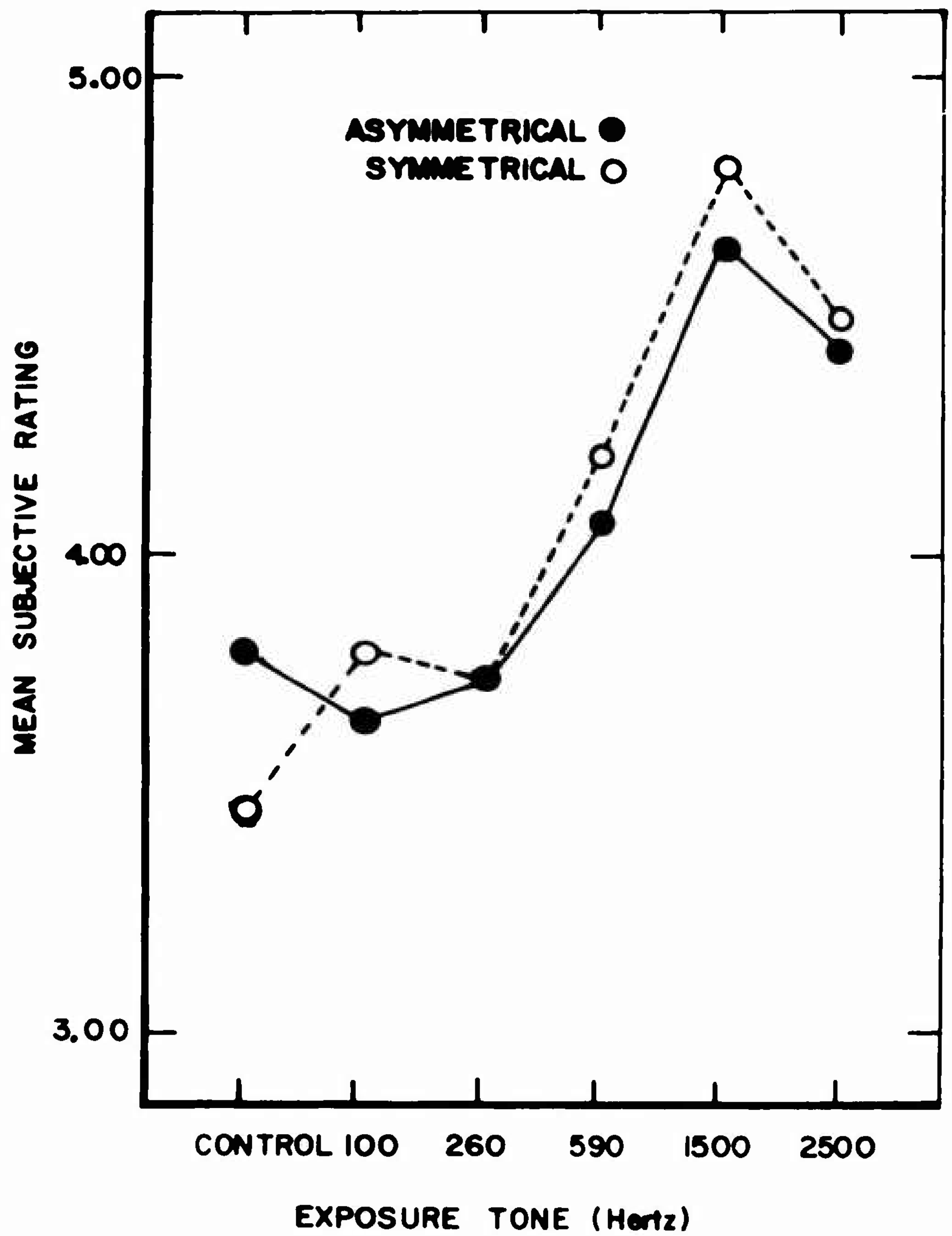

Figure 4. Mean Subjective Rating for Each Stimulus Frequency for Asymmetrical and Symmetrical Exposures.

SECTION IV.
Discussion

The results seem clear in supporting the hypothesis that the eyes open portion of the Rail Task is sensitive to stimulus frequencies found in previous studies to produce the most direct effects on the vestibular system. In particular, 1500 Hz when presented in an eyes open asymmetrical exposure condition produced more adverse effects on the ability of subjects to balance on the rails than did the control and the other frequencies used in the experiment (although, the difference between 1500 and 280 Hz and 2500 Hz did not reach the level of statistical significance).

A decrement was also found at 590 Hz relative to the control condition for the symmetrical exposure group. However, 590 Hz was not significantly different from the other frequencies used in the experiment. On a statistical basis, the difference between 590 Hz and the control condition should be assumed to reflect chance factors since in the fifteen comparisons conducted among frequency conditions for the group it is not surprising to find one significant difference due to chance.

The Friedman Two Way Analysis of Variance for Ranks yielded a probability level of $p<.30$, which would support this interpretation. Also, the fact that the decrement was obtained on only the 1¼-inch rail and not on the ¾-inch rail casts still further doubt on the validity of this finding.

Whether or not future research finds 590 Hz to be a frequency, the vestibular system of normal individuals is particularly sensitive to the results of the present experiment seem to support the Rail Task as being sensitive to vestibular variables since the decrement at 1500 Hz appears to be a valid response. This result occurred within the frequency range where Ades (ref 1) reported that individuals perceived a slight shift in the visual field at the lowest intensity level.

The results also reaffirm findings in previous studies that asymmetrical exposure has a more adverse effect on equilibrium than symmetrical exposure (ref 4, 6).

The fact that the eyes closed measure did not show sensitivity to the pure tone stimulus is consistent with the results obtained in previous studies (ref 4, 6). In five previous groups a significant decrement was not found in the eyes closed performance on the rails as a function of intensity of noise stimulation. This measure seems clearly insensitive to the effects of high intensity noise on human equilibrium. It would seem advisable in future studies to increase the reliability of the eyes open measure by including additional trails, and to drop the eyes closed measure since it adds little or no information. The result should be a measure more sensitive to the effects of acoustic stimulation.

The subjective data were obtained primarily to determine if the response showed the same pattern of decrement as that found on the Rail Task. If so, one might conclude that the decrement on the rails was due primarily to the distracting or stressful nature of the acoustical stimulation. Although 1500 Hz produced the higher subjective rating and the greater decrement on the rails in the asymmetrical exposure condition there is little similarity for the other frequencies. For example, 2500 Hz was rated high subjectively and this rating differed little from the rating at 1500 Hz, yet no decrement was found on the Rail Task at 2500 Hz for either asymmetrical or symmetrical exposure. Also, the symmetrical exposure group gave 1500 Hz the highest rating (as did the asymmetrical group), yet no decrement was found at this frequency for this group. We can conclude that at best there is only a slight relationship between the subjective rating of the noise and the decrement obtained on the Rail Task.

Of particular interest in the present experiment is the possibility that the vestibular system may be stimulated by noise at surprisingly low intensity levels. Ades (ref 1) found that the slight shift in the visual field for his subjects occurred at approximately 135 dB at 1500 Hz. In the present study, a decrement in the ability to balance on the rails at this frequency with eyes open occurred at 95 dB in the left ear and 75 dB in the right ear. Although there are other possible explanations for the results of the present study, the evidence suggests the direct effect of acoustic energy on the vestibular system at low intensity levels where there is an asymmetrical presentation of the stimulus to the ears.

The fact that a decrement in performance on the eyes open part of the Rail Task were obtained at frequencies found to produce nystagmus and a shift in the visual field at much higher intensity levels suggests that the Rail Task is more sensitive than previous measures of the effects of noise on the vestibular system. This result is not surprising since Ades et al (ref 2) reported that his deaf subjects often reported dizziness before their threshold of nystagmus was reached. In addition, since proprioceptive reflexes function for the most part without conscious awareness, it is not surprising that performance on the rails was adversely affected at lower intensity levels than are necessary to elicit subjective symptomotology characteristic of vestibular stimulation.

In spite of the sensitivity of the Rail Task, it gives us very little insight into the manner in which acoustic stimulation affects the vestibular system. More analytical measures in addition to the Rail Task will be used in future studies. One hypothesis of how noise affects equilibrium is that the subject's perception of the vertical is affected by direct action of the noise on the saccules or utricles or both of the inner ear. Therefore, the subject's perception of the vertical and observations of the counterrolling of their eyes will be examined in future studies at the same frequencies used in the present experiment.

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13. ABSTRACT

The ability of subjects to balance on narrow rails was measured during exposure to pure tones of 100, 260, 590, 1500, and 2500 Hz and a control condition. One group of subjects was presented the test stimulus at intensity levels of 95 dB (re 0.0002 dyne/sq cm) in the left ear and 75 dB in the right ear (asymmetrical exposure). The other group was presented the tones at a level of 95 dB in both ears (symmetrical exposure). A decrement in rail performance occurred at 1500 Hz for the asymmetrical exposure group and at 590 Hz for the symmetrical exposure group. The decrement determined with symmetrical exposure was less than the decrement found with asymmetrical exposure. This result supports previous findings that asymmetrical exposure has more adverse effects on human equilibrium than symmetrical exposure. Both frequencies at which decrements occurred have been found in previous studies to have the lowest threshold for vestibular stimulation as determined by a slight shifting of the visual field in normal hearing subjects and by nystagmus measures in deaf individuals. Therefore, the results of the present study are interpreted as a possible demonstration of the direct effects of noise on the vestibular system.

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